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Formulation of Lempuyang Essential Oil Lotion (*Zingiber zerumbet* (L.) Smith) as a Mosquito Repellent

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ABSTRACT: *Mosquito-borne diseases, such as malaria, pose a significant public health threat in Indonesia, with cases increasing to 400,000 in 2023. This study focuses on developing a natural mosquito repellent lotion using lempuyang (Zingiber zerumbet (L.) Smith) essential oil, known for its insecticidal properties, as a sustainable and eco-friendly alternative to synthetic repellents. The objective of this study is to formulate and evaluate a mosquito repellent lotion using lempu–yang essential oil at varying concentrations (5%, 10%, and 15%) and assess its physical properties, safety, and repellent efficacy. Lempuyang essential oil was extracted via steam distillation from fresh rhizomes. Lotion formulations were prepared with different oil concentrations and evaluated for organoleptic properties, homoge–neity, emulsion type, pH, spreadability, and stability. Skin irritation tests were conducted and mosquito repellent efficacy was tested using Culex sp. mosquitoes in a controlled environment. The essential oil extraction via steam distillation yielded 0.4% oil from fresh lempuyang rhizomes, producing a pale yellowish-white oil. All lotion formulations exhibited desirable organoleptic properties, homogenity, and spreadability (5–7 cm), with pH levels (6.18–7.46) suitable for skin application. Stability tests confirmed no changes in appearance, color, or odor over four weeks. Irritation tests showed no adverse reactions, confirming the lotion's safety. The 15% formulation demonstrated the highest mosquito repellent efficacy, providing 82.45% protection, outperforming the 5% and 10% formulations. These results highlight the 15% lempuyang essential oil lotion as a promising, natural, and safe mosquito repellent.*

Keywords: *essential oil; lempuyang; lotion; mosquito repellent; Zingiber zerumbet*

1. Introduction

Mosquitoes are a common nuisance in daily life in Indonesia and pose a major public health concern [1]. One of the primary dangers associated with mosquito bites is the transmission of various diseases, including malaria, which can be life-threatening [2]. According to the Ministry of Health of The Republic of Indonesia, malaria cases in Indonesia have been on the rise. In 2021, more than 300,000 cases were reported with 705 deaths, and this number increased to 400,000 cases in 2023 [3]. These alarming statistics emphasize the urgent need for effective and sustainable mosquito control strategies to mitigate disease transmission.

One promising approach for mosquito control involves the use of plant-derived essential oils, such as those from lempuyang (*Zingiber zerumbet* (L.) Smith). Traditionally, lempuyang has been used in Indonesia as a medicinal plant with diverse biological activities, including anti-inflammatory, antimicrobial, and insecticidal properties [4–7]. Studies have demonstrated its antimicrobial efficacy against fungi such as *Aspergillus flavus*, *A. ochraceus*, and *A. niger* [8]. Additionally, lempuyang essential oil has shown toxicity against pests like *Lasioderma serricorne* [9]. Furthermore, dichloromethane and methanol extract of lempuyang effectively killed *Anopheles nuneztovari* and *Aedes aegypti* larvae [5] . More recent reports also confirm the essential oil's potent activity against *Culex quinquefasciatus* and *Aedes albopictus* larvae, two important vectors of urban mosquito-borne diseases [10]. These findings underscore the potential of lempuyang essential oil as a natural and effective mosquito control agent, making it a strong candidate for anti-mosquito product development.

The concentrations of 5%, 10%, and 15% lempuyang essential oil used in the lotion formulation were selected to represent a safe and potentially effective range for topical use, as supported by previous research. Lempuyang essential oil has shown strong larvicidal effects in aqueous assays, with LC_{50} values as low as 21.81 µg/mL against *Culex quinquefasciatus*, suggesting significant biological activity at low concentrations [10]. This evidence justifies the use of the selected concentrations in the development of the repellent formulation. In addition to developing the formulation, the physical and functional properties of the lotion, including organoleptic properties, homogeneity, emulsion type, pH, spreadability, and stability, were evaluated. The repellent activity of the lotion was also be tested to assess its ability to protect against mosquito bites. This study seeks to provide an effective, natural, and environmentally friendly alternative to synthetic repellents for mosquito control.

2. Methods

2.1. Plant material and essential oil extraction

Lempuyang rhizomes were obtained from Karo Regency, North Sumatera, Indonesia, located at coordinates 3°10′N, 98°53′E, at an altitude of approximately 1200 meters above sea level. The plant material was authenticated by Herbarium Medanense (MEDA) (No: 2226/2024/MEDA) Universitas Sumatera Utara.

2.2. Essential oil extraction

The essential oil was extracted from the rhizomes of lempuyang using steam distillation [11]. A total of 500 g of fresh lempuyang rhizomes was placed in the flask of a steam distillation apparatus, and appropriate distilled water was added to ensure sufficient steam contact with the sample. The apparatus was sealed, and the water was heated to boiling, generating steam through the powdered material. The heat from the steam caused the volatile essential oil to vaporize, and the vapor mixture of essential oil and water was carried into a condenser. The vapor was cooled, condensed, and collected in a receiving flask as a liquid mixture. The condensate was transferred to a separating funnel and allowed to settle, enabling the separation of the essential oil layer from the aqueous phase. This process was repeated for

a total of 15 kg of fresh lempuyang rhizomes, divided into multiple 500 g sections to optimize the efficiency of the distillation process and maintain the quality of the extracted oil. The less dense essential oil was carefully collected and dried with 2 g of anhydrous sodium sulfate to remove residual moisture [12]. The dried essential oil was filtered to ensure purity and then stored in a dark glass vial at 4°C.

2.3. Formulation of lempuyang essential oil lotion

The formulation of lempuyang essential oil lotion was carried out using a stepwise process. First, all required ingredients (Table 1) were accurately weighed. Cetyl alcohol, stearic acid, and lanolin were combined in a porcelain dish and melted over a water bath at a temperature of 70°C to form Phase I. Concurrently, methylparaben and triethanolamine were dissolved in distilled water and heated to 70°C to prepare Phase II, ensuring both phases were at the same temperature prior to emulsification. Phase II was then transferred into a preheated mortar, and Phase I was gradually added with constant stirring until the mixture's temperature decreased. When the temperature reached approximately 45°C, lempuyang essential oil, pre-mixed with glycerin, was incorporated into the mixture with continuous stirring to ensure homogeneity. Finally, the resulting lotion was transferred into suitable containers for storage.

2.4. Evaluation test of lotion formulation

The lotion formulation was evaluated for organoleptic properties, homogeneity, emulsion type, spreadability, pH, and stability. Organoleptic properties (color, texture, and odor) were assessed visually and manually to ensure the formulation's acceptability. Homogenity was tested by spreading a small sample on a glass slide to confirm uniform distribution without visible coarse particles [13]. The emulsion type was conducted using a small amount of lotion placed on a glass slide, and one drop of methylene blue dye was added [14]. The sample was stirred gently and covered with a cover slip. The emulsion type was determined by observing the distribution of the dye under a microscope. Uniform dye dispersion indicated an oil-in-water (O/W) emulsion, while the appearance of blue spots indicated a water-in-oil (W/O) emulsion. The spreadability of the lotion was evaluated by placing a defined amount of the sample between two glass plates under a specific weight and measuring the diameter [15]. The pH of the formulation was determined using a digital pH [15]. For the physical stability test, the lotion was stored at room temperature (25°C ± 2°C) with exposure to light for 30 days [16]. Observations for changes in shape, color, and odor were recorded periodically to assess the physical stability of the product.

2.5. Irritation test

The irritation test was conducted on 20 human volunteers to evaluate the safety of the lotion formulation. A sample of 500 mg of the lotion was applied to an area behind the ear with a diameter of approximately 3 cm [17]. The application site

Table 1. Formulation design for lempuyang essential oil lotion

Ingredient name	F0	F1	F2	F3	Function
Lempuyang essential oil (%)	-	5	10	15	Active ingredient
Stearic acid (g)	10	10	10	10	Emulsifier
Lanolin (g)	2	2	2	2	Lotion base
Cetyl alcohol (g)	3	3	3	3	Thickener
Glycerin (g)	15	15	15	15	Humectant
Triethanolamine (g)	3	3	3	3	Alkalizing agent
Methylparaben (g)	0.3	0.3	0.3	0.3	Preservative
Distilled water ad (g)	100	100	100	100	Solvent

was left undisturbed for 9 hours, after which the skin was examined for any signs of adverse reactions. Observations focused on visible changes, including redness (erythema), itchiness (pruritus), or swelling (edema) of the skin. Any occurrence of these reactions was recorded to assess the potential irritation caused by the formulation.

2.6. Mosquito breeding model

The breeding of *Culex sp*. mosquitoes was conducted in a controlled environment in the laboratory. Larvae were collected and placed in small containers filled with water to mimic their natural habitat, then transferred to a laboratory insectary. The rearing conditions were maintained at a room temperature of 25 ± 2°C, relative humidity of 75 ± 5%, and a 12 hours light–dark cycle to simulate natural environmental conditions [18]. The larvae were fed daily with finely ground fish food for proper nutrition and growth. Over 7 days, the larvae transformed into pupae, which subsequently developed into adult mosquitoes within 2–3 days. Adult female mosquitoes, aged 5–7 days, were housed in standard-sized wooden cages with a sleeve opening on one side for handling. The mosquitoes were provided with 10% sucrose solutions ad libitum as a source of nourishment. Before testing, the adult mosquitoes were starved for 24 hours to standardize their feeding behavior during the antimosquito activity test [19,20].

2.7. Mosquito repellent efficacy

The effectiveness of the lempuyang lotion formulation was tested using 20 healthy volunteer panelists, divided into five groups: Group I (blank control, 4 panelists using a formulation without active ingredients), Group II (4 panelists using a 5% concentration), Group III (4 panelists using a 10% concentration), Group IV (4 panelists using a 15% concentration), and a positive control group (4 panelists using a commercially available mosquito repellent lotion, Soffel). Fresh, unfed adult *Culex sp*. mosquitoes (20 per cage) were used in confinement cages to ensure consistent biting behavior during the test. The lotions were evenly applied to the panelists wrists, which were then exposed to mosquitoes for an initial 5-minute interval followed by four additional 5-minute intervals, with one-hour rest periods between exposures. After each lotion formula test, the mosquitoes were replaced with new, unfed mosquitoes to maintain consistency. Mosquito landings were recorded manually by trained observers, focusing only on the exposed wrist area, while the rest of the hand and arm were covered with fabric to eliminate unintended contact and ensure consistent observation. Effectiveness was calculated using the protection power formula: $Dp = [(K - P)/K] \times 100\%$, where Dp represents the protection power, K is the number of landings on wrists treated with the blank control (lotion without lempuyang essential oil), and P is the number of landings on wrists treated with the Lempuyang lotion. The study was conducted in accordance with ethical guidelines, and informed consent was obtained from all participants. Ethical approval was granted by the Komite Etik Penelitian (KEP) of Institut Kesehatan Deli Husada Deli Tua under approval number 2387/KEP-IKDH/XII/2024.

3. Results and discussion

3.1. Lempuyang essential oil distillation

The extraction of lempuyang essential oil was performed using steam distillation with distilled water as the solvent. Fresh lempuyang rhizomes weighing 15 kg were used as raw material. The process produced 60 mL of essential oil, which appeared pale yellowish white, indicating its clarity and quality (Figure 1). The yield percentage was determined to be 0.4%, calculated by dividing the oil volume by the weight of the raw material and multiplying by 100. This yield is typical for steam distillation of fresh plant materials like lempuyang [21]. These findings are important for evaluating the process's efficiency and its potential scalability for producing sufficient quantities for use in formu-

Figure 1. Lempuyang essential oil obtained through steam distillation, showing a pale yellow oil layer stored in a sealed glass vial

Figure 2. Visual appearance of the prepared Zingiber zerumbet (lempuyang) lotion formulations with increasing concentrations of essential oil. From left to right: F0 (blank control without essential oil), F1 (5% essential oil), F2 (10%), F3 (15%), and F4 (positive control using commercial repellent). The gradual change in color and opacity corresponds to the increasing concentration of lempuyang essential oil in the formulation

lations, such as an antimosquito lotion. To further enhance yield and scalability, advanced extraction methods such as continuous steam distillation, microwave-assisted extraction, or supercritical fluid extraction may be considered. These techniques can improve oil recovery, reduce processing time, and support large-scale production.

3.2. Evaluation of lempuyang essential oil lotion

3.2.1. Organoleptic properties

The organoleptic evaluation of the lempuyang essential oil lotion formulations assessed their appearance, color, odor, and texture. All formulations, including the base lotion (F0) and those containing 5% (F1), 10% (F2), and 15% (F3) lempuyang essential oil, exhibited satisfactory characteristics. The lotions had a smooth and creamy texture without visible particles or phase separation, ensuring uniform consistency. The base lotion (F0) appeared white, while F1–F3 displayed a gradual yellowish tint corresponding to the increasing concentration of essential oil (Figure 2). In terms of odor, F0 was neutral and odorless, while F1–F3 emitted a mild herbal scent, with the fragrance intensity increasing alongside the essential oil concentration. These results demonstrate that the formulations possess appealing sensory attributes, enhancing their potential acceptability for consumer use.

3.2.2. Homogeneity test

The homogeneity of the lempuyang essential

oil lotion formulations was evaluated to ensure uniformity in the distribution of ingredients. A visual inspection was performed by spreading the lotion on a transparent glass surface to detect any coarse particles or phase separation (Figure 3). The results confirmed that all formulations, including the base lotion without essential oil (F0) and the formulations containing 5% (F1), 10% (F2), and 15% (F3) lempuyang essential oil, were homogeneous with the absence of visible particles or phase separation.

3.2.3. Emulsion type and spreadability test

The type of emulsion in the lotion formulations was determined using the methylene blue solubility test. All formulations, including the control (F0) and those containing essential oil (F1–F3), were found to dissolve methylene blue, indicating that they are oil-in-water (O/W) emulsions. This type of emulsion is preferred for topical products due to its lightweight, non-greasy feel, and compatibility with skin. The spreadability test was conducted to evaluate the ability of the lotion formulations to spread on the skin. The base lotion (F0), likely due to the absence of essential oil, exhibited the highest spreadability (6 cm), while the formulations containing lempuyang essential oil exhibited slightly lower values. Specifically, F1 (5% oil) and F2 (10% oil) both showed a spreadability of 5 cm, and F3 (15% oil) displayed a spreadability of 5.5 cm. These values are within the acceptable range of 5–7 cm, indicating that all formulations provide good spreadability and are suitable for application on the skin [22].

3.2.4. pH stability test

The pH of the formulations was monitored weekly over a four-week period to ensure stability and compatibility with skin. The base lotion (F0) maintained a stable pH of 6.18 throughout the observation period. Formulations containing lempuyang essential oil exhibited slightly higher pH values: F1 (5% oil) had a pH of 6.88, F2 (10% oil) had a pH of 7.28, and F3 (15% oil) had a pH of 7.46. The pH values of all formulations were within the acceptable range of 4.5–8, as specified by Indonesian National Standard (SNI 4399) for cosmetic products especially for lotion products. This range ensures that the formulations are safe for use on the skin, as they align with the natural pH of the skin and do not cause irritation [23]. The stability of the pH values throughout the observation period further indicates the integrity and consistency of the formulations during storage. These results indicate that all formulations remained stable and within a suitable pH range for skin products.

Figure 3. Homogeneity test of lempuyang lotion formulations on glass slides. From left to right: F0 (blank), F1 (5% essential oil), F2 (10%), and F3 (15%). Each sample was spread on a clean glass surface to visually assess the uniformity of the formulation. All formulations showed even distribution without visible phase separation or clumping, indicating good homogeneity

3.2.5. Physical stability test

The physical stability of the formulations was evaluated over a four-week period, focusing on changes in appearance, color, and odor. None of the formulations (F0–F3) exhibited any alterations in these characteristics during the observation period, indicating good physical stability (Table 2). This suggests that the formulations are robust and capable of maintaining their quality under normal storage conditions.

3.2.6. Irritation test

A skin irritation test was conducted on 20 volunteers and left undisturbed for 9 hours to ensure the safety of the lotion formulations (Figure 4). The study monitored signs of redness, itching, or swelling after application of the formulations. No adverse reactions were observed for any of the formulations (F0–F3) among the participants, demonstrating that the lotion is safe for use on the skin. These findings confirm that the formulations are non-irritating and suitable for repeated use. The irritation test results are outlined in Table 3.

3.3. Results of mosquito-repellent effectiveness on skin

The average results of mosquito-repellent effectiveness highlight the significant impact of lempuyang essential oil in providing protection (Figure 5). The base lotion (F0), which lacked essential oil, demonstrated no protective effect with an average protection of 0%, confirming its

Table 2. Observation results of changes in shape, color, and odor of lotion formulations

Observation	Formulation	Week 1	Week 2	Week 3	Week 4
Shape	F0	-	-	-	-
	F1	-	-	-	-
	F2	-	-	-	-
	F3	-	-	-	-
Color	F0	-	-	-	-
	F1	-	-	-	-
	F2	-	-	-	-
	F3	-	-	-	-
Odor	F0	-	-	-	-
	F1	-	-	-	-
	F2	-	-	-	-
	F3	-	-	-	-

Figure 4. Representative photographs showing the skin condition of panelists 9 hours after application of lotion formulations. No visible signs of irritation (such as redness, swelling, or rash) were observed in any group: (F0) blank control, (F1) 5% essential oil, (F2) 10%, and (F3) 15%. These results confirm the formulations dermal safety under the tested conditions

Table 3. Observation results of changes in shape, color, and odor of lotion formulations

Formula	Volunteers	Observations		
		Redness	Itching	Swelling
F0	1	-	-	-
	2	-	-	-
	3	-	-	-
	4	-	-	-
	5	-	-	-
F1	6	-	-	-
	7	-	-	-
	8	-	-	-
	9	-	-	-
	10	-	-	-
F2	11	-	-	-
	12	-	-	-
	13	-	-	-
	14	-	-	-
	15	-	-	-
F3	16	-	-	-
	17	-	-	-
	18	-	-	-
	19	-	-	-
	20	-	-	-

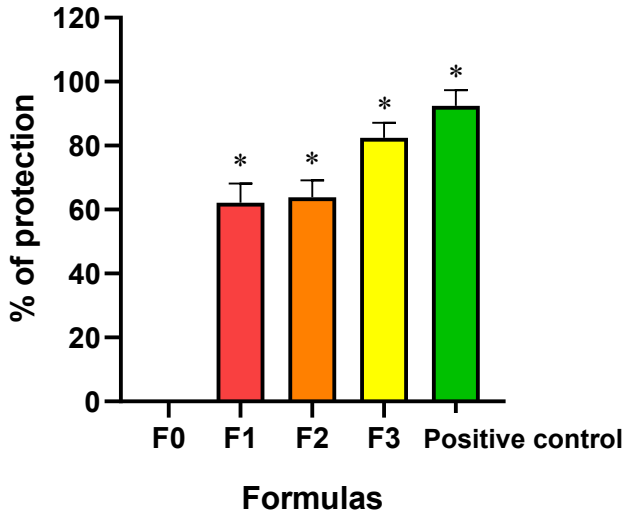

Figure 5. Results of mosquito-repellent effectiveness on skin. The mosquito-repellent effectiveness of the lotion formulations was assessed by applying the lotion to the skin and exposing the hand to a mosquito enclosure (box). Protection percentages were measured at four 5-minute intervals, and the average effectiveness for each formulation was calculated. *p < 0.05 vs. F0

inability to repel mosquitoes. Among the formulations containing lempuyang essential oil, a clear trend was observed where higher concentrations of the oil resulted in increased effectiveness. The formulation with 5% essential oil (F1) provided moderate protection with an average of 62.13%, while the 10% essential oil formulation (F2) showed a slight improvement at 63.83%, indicating that doubling the essential oil concentration led to only a marginal increase. The 15% essen-

tial oil formulation (F3), however, achieved a significantly higher average protection of 82.45%, demonstrating the greatest effectiveness among the tested formulations. The commercial product (Soffell), used as a positive control, achieved the highest protection with an average of 92.44%, serving as a benchmark for comparison. Although the 15% formulation did not exceed the commercial product efficacy, its natural composition, comparable protection, and lack of irritation make it a promising alternative—especially for individuals with sensitive skin or concerns about synthetic chemicals. Although F3 did not reach the protection level of the commercial product, it showed comparable effectiveness, highlighting its potential as a natural and effective alternative. These findings suggest that a 15% concentration of lempuyang essential oil is optimal for achieving high mosquito-repellent efficacy. To further enhance the mosquito-repellent efficacy and reach a level comparable to the commercial product, future formulation improvements could involve combining lempuyang essential oil with other synergistic plant-based oils or incorporating the active compound into nanoemulsion or encapsulated delivery systems. These strategies may improve both the duration of repellency and adherence to the skin.

The 15% lempuyang essential oil lotion was chosen as the most suitable formulation based on both its high repellent activity (82.45%) and supportive physical characteristics. It demonstrated a smooth and uniform consistency, formed a stable oil-in-water emulsion, had good spreadability (5.5 cm), and maintained a skin-compatible pH of 7.46. Throughout the 4-week storage period, no changes in color, odor, or texture were observed. Furthermore, it did not cause any irritation in human volunteers. These combined findings confirm the 15% formulation as the most effective, stable, and safe option.

The effectiveness of this formulation is likely due to the bioactive components in lempuyang, which disrupt mosquitoes' ability to locate and bite humans [24]. This aligns with the growing interest in plant-based repellents as safer alternatives to synthetic options. A major benefit of lempuyang essential oil lotion is its natural composition, which minimizes health risks compared to chemical repellents like diethyltoluamide (DEET) [25]. Synthetic repellents, though effective, can cause skin irritation or neurotoxicity with prolonged use [26,27]. In contrast, lempuyang is non-toxic and eco-friendly, making it suitable for sensitive individuals, including children and pregnant women [28]. Additionally, lempuyang essential oil lotion may provide secondary benefits. Traditionally, lempuyang has been used for its anti-inflammatory and antimicrobial properties, suggesting the lotion could help soothe skin irritated by mosquito bites [4,29,30]. Its pleasant aroma also enhances user comfort, unlike the strong, often unpleasant smell of many synthetic repellents. Despite these advantages, there are limitations to address. The repellent's effectiveness may vary based on environmental factors, application frequency, and skin type. Future research could explore combining lempuyang with other natural ingredients or advanced delivery systems to enhance its performance.

4. Conclusion

In summary, the 15% lempuyang essential oil lotion formulation shows promise as a natural, safe, and effective mosquito repellent. Its potential skin-soothing properties and user-friendly nature make it a compelling alternative to synthetic options. Further research should focus on optimizing the formulation, conducting real-world trials, and addressing production challenges to support its use in mosquito control strategies.

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